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RESEARCH IN RADIATION PHYSICS AND AERODYNAMICS

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I. INTRODUCTION AND SUMMARY

The current ARPA/IPAPS program as defined in UCSD Continuation Proposal 4769 dated January 4, 1972 and in the U.S. Army Research Office-Durham Contract DAHC04-72-C-0037 dated June 12, 1972, called for the performance of advanced interdisciplinary research in support of strategic defense technologies and ARPA objectives. This research, with primary emphasis on the physics of turbulent flow, plasmas and lasers, shall include but not necessarily be limited to the following areas:

a. Wake Turbulence and Atmospheric Boundary Layers. Experimental and theoretical studies involving variable temperature effects, entrainment, mixing, chemical reactions in both wake turbulence and atmospheric boundary layer as appropriate, and also turbulence in stratified flows.

b. Turbulent Mixing and Shear Flows. Basic studies of turbulent mixing and shear flows.

c. High-temperature Gas Dynamics. Basic gas dynamics research involving radiation, chemical reactions, kinetics, and turbulence.

d. Ionospheric Physics. Theoretical analysis related to an ionospheric heating experiment in which a high power radio wave transmitter was used to modify the ionosphere, including the analysis of plasma instabilities postulated as being responsible for the observed effects.

e. Laser Propagation and Advanced Technology. Theoretical and experimental studies of laser energy propagation and advanced laser technology.

f. Laser Diagnostics and Interactions. Development of laser diagnostic techniques and investigations of nonlinear interactions.

As reported at the recent ARPA/STO-Institutional Research Review Briefing,* our current research at the Institute for Pure and Applied Physical Sciences under Contract No. DAHC04-72-C-0037 covers twenty-six major topics. The research is being carried out by fifteen faculty members,

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*S. C. Lin, "Update and Review of Institutional Research -IPAPS/UCSD," oral presentation at the ARPA/STO-Institutional Research Review Briefing, Washington, D.C., 28 September 1972.

four post-doctoral research engineers, eighteen graduate students, and a number of undergraduate summer students. A summary of the research topics, together with the names of the participating investigators, are given in Table 1 below. It is important to note that these research topics were not randomly chosen, but rather a logical set derived from a natural matching of research interests between ARPA and IPAPS participants. It is also important to note that as a result of effective and continuing communication between IPAPS and ARPA/STO technical personnel, all the on-going research topics are very much relevant to the current and projected ARPA programs. This is illustrated by the correlation chart shown in Table 2. While a detailed account of progress in each project is clearly out of the scope of the present report (as it would be more appropriately done through our regular scientific journal publications) the following sampling of our recent accomplishments in some of the research topics (referring to identification numbers given in Table 1) and a brief report of progress in the next two sections may serve to highlight the dynamism of the current IPAPS program and illustrate our responsiveness to immediate as well as longer range ARPA research needs.

II. HIGHLIGHTS OF RECENT ACCOMPLISHMENTS

Topic #1. High Temperature Entrainment

Professor S. C. Lin, Dr. C. P. Wang, and student Leslie Tsang have demonstrated that hot air bubbles of 1 kjoule thermal energy range can be successfully generated in the laboratory for high-temperature entrainment studies, using the exploding-wire-initiated pulsed arc method. Using stationary and rotating fine-wire thermometer probes, they have also made quantitative measurements of the fluctuating temperature field within the turbulent thermal bubble.

Even though the Reynolds number associated with the rising bubble motion was only of the order of 5×10^3, the entrainment process was found to be strongly turbulent, and the temperature fluctuation spectrum appeared to converge rapidly as the number of statistical samples increases. In fact, by invoking passive scalar mixing theories and assuming local equilibrium spectral transfer, the averaged turbulence kinetic energy dissipation rate within the bubble can be estimated from the apparent diffusive cutoff wave number observed in these preliminary experiments to be of the order of $0.06\ (U^3/2D)$, where U and D are, respectively, the instantaneous rise velocity and mean diameter of the bubble. This implied a very rapid spectral energy transfer process since the turbulence kinetic energy per unit mass within the bubble was at most of the order of $U^2/2$, while the large eddy lifetime must be at least of the order of D/U.

Table 1. Current Research Topics at IPAPS Sponsored by ARPA

Topic Number	Description	Investigators
1	High temperature entrainment	Lin, Wang, and student
2	Strong temperature mixing by turbulence	Lin and Samuel Lin
3	Turbulence in stratified flow	Yeh, Van Atta, and Lin
4	Turbulence in atmospheric boundary layer	Van Atta and students
5	Scalar mixing and turbulent shear flow	Gibson and student
6	Turbulent flows with fast chemical reactions	Gibson
7	Scalar diffusion and space-time correlation in turbulent flow	Libby and student
8	Possible application of L^* instability to laser	Williams and student
9	Effect of radiation on blast waves	Olfe and student
10	2-dimensional radiative transfer	Olfe and student
11	Gas-surface interactions	Miller and student
12	Chemical reactions in crossed molecular beams	Miller and student
13	Shock tube measurements of metal oxides f-numbers	Penner, Sulzmann, and student
14	Non-linear phenomena in bound-free transitions induced by lasers	Penner and student

Table 1. (Continued)

Topic Number	Description	Investigators
15	Laser-induced stress wave propagation in solids and liquids	Ellis and student
16	Laser-induced elastic wave focusing in partially transparent solids	Nachbar and student
17	Impulsive stress wave propagation in solids	Hegemier and student
18	Laser-induced plasma instabilities	Brueckner and Jorna
19	High-power CW visible laser	Lin and Wang
20	Magnetic confinement and efficient ion laser generation	Lin and student
21	Upward laser fequency conversion in gaseous media	Lin and student
22	Kinetics in electron-beam-seeded gas lasers	Lin and Wang
23	Raman scattering and advanced laser diagnostics	Lin, Wang, and students
24	ELF radio propagation	Booker
25	Theory of ionospheric heating	Fejer and students
26	Non-linear interaction between electromagnetic waves and plasmas	Lewak and students

Table 2. Correlation between IPAPS Research & ARPA/STO Programs (referring to topic number given in Table 1).

ARPA/STO Program / IPAPS Research	Laser Physics	Laser Interaction & Optics	Underwater Technology	Ivy Owl	Plume	Others (Reentry, Arecibo, etc.)
Booker			24			24
Brueckner		18				
Ellis		15	15			
Fejer						25
Gibson		5	5, 6			6
Hegemier		17				
Lewak						26
Libby			7	7	7	7
Lin, Wang	19, 20, 21, 22	19, 22	3, 19, 20, 23	1, 2	2	2
Miller	12	11		12	11, 12	
Nachbar		16				
Olfe		9		9, 10		9
Penner, Sulzmann	14	14		13	13	
Van Atta, Yeh		4	3, 4			
Williams	8					

If the macroscopic entrainment motion were relatively insensitive to the Reynolds number, and the temperature mixing behavior can, indeed, be extrapolated to much larger scale explosion phenomena, then the very strong root-mean-square temperature fluctuation (of the order of 50 percent the mean temperature difference between the inside and outside of the bubble) observed in these small scale experiments indicate that "laminar code" calculations of chemical reactions and radiation properties of hot air clouds may lead to serious errors. The important implications of these important findings were promptly communication to Mr. Robert A. Moore and Col. Paul Baker by S. C. Lin during his visit to ARPA/STO in December, 1971, and also to the larger DOD community during a recent talk by S. C. Lin at the DNA Chemistry Conference in Washington, D.C., 12 September 1972.

This research is continuing. Recent experimental efforts are being directed toward improving the initial symmetry and increasing the energy yield of the thermal bubble. In the concurrent theoretical program, Dr. C. P. Wang is investigating the effects of density stratification and of turbulent mixing on the rising motion of the buoyant thermal.

Relevant publications generated from this work include the following:

(1) S. C. Lin, "Laboratory Simulation of High-Temperature Entrainment," Proceedings of the ARPA Entrainment Workshop, Riverside Research Institute, New York, N.Y., October 20-21, 1970.

(2) S. C. Lin and C. P. Wang, "Generation of Isolated High-Temperature Thermals by Pulsed Arc Discharges," Bull. Am. Phys. Soc., Series II, 16, 1312 (1971).

(3) C. P. Wang and S. C. Lin, "Measurements of Mass Entrainment and Turbulent Mixing in Isolated Thermals," Bull. Am. Phys. Soc., Series II, 16, 1313 (1971).

(4) C. P. Wang, "Motion of an Isolated Buoyant Thermal," Phys. Fluids 14, 1643 (1971).

(5) S. C. Lin, L. Tsang, and C. P. Wang, "Temperature Field Structure in Strongly-Heated Buoyant Thermals," Phys. Fluids 16, December, 1972.

(6) C. P. Wang, "Motion of a Turbulent Buoyant Thermal in a Calm, Stably-Stratified Atmosphere," (submitted to Physics of Fluids).

Topic #5. Scalar Mixing and Turbulent Shear Flow

Professor C. H. Gibson and his students continued to make significant progress on a number of basic research problems involving scalar mixing by turbulence. With the help of major funding support from outside of the ARPA/IPAPS program, his research team has also made extensive field measurements on atmospheric and oceanic turbulence. Especially worth mentioning is a recent study funded jointly by the National Science Foundation and the Air Force Cambridge Research Laboratories on the effects of temperature and humidity on density and refractive index fluctuations over the open ocean. The results may be of considerable importance in a number of problems related to laser and optical propagation through the earth's atmosphere.

Relevant publications are as follows:

(1) C. H. Gibson and J. P. Clay, "Measurements of Turbulent Temperature in Mercury, Air and Water," paper presented at the IUTAM 13th Congress, Moscow, August 1972.*

(2) J. P. Clay and C. H. Gibson, "Power Law Comparison of Turbulent Temperature Spectra," Abstract for the 25th Annual Meeting for the Division of Fluid Dynamics of the Am. Phys. Soc., November 1972.*

(3) L. A. Vega, J. P. Clay and C. H. Gibson, "Fine Scale Measurements of Velocity and Temperature in the Mixed Layer of the Ocean," Abstract for the 25th Annual Meeting for the Division of Fluid Dynamics of the Am. Phys. Soc., November 1972.*

(4) G. R. Stegen, C. H. Gibson and C. A. Friehe, "Measurement of Momentum and Sensible Heat Fluxes over the Open Ocean," J. Phys. Oceanog., (scheduled for publication in January 1973).*

(5) C. H. Gibson and R. B. Williams, "Measurements of Turbulence and Turbulence Mixing in the Pacific Equatorial Undercurrent," Proceedings of the International Symposium on Oceanography of the South Pacific, Wellington, New Zealand, February 1972, (to be published in August 1973).*

(6) C. A. Friehe, C. H. Gibson and G. F. Dreyer, "Effects of Temperature and Humidity on Density and Refractive Index Fluctuations over the Open Ocean," paper to be presented at the Optical Society of America Annual Meeting, October 1972.**

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*Partial support from ARPA/IPAPS acknowledged
**Supported by NSF-SA-28366 and AFCRL F 19628-10-C-0054 grants.

Topic #15. Laser-Induced Stress Wave Propagation in Solids and Liquids

Professor A. T. Ellis and graduate student Mike Felix have demonstrated that stress wave trains of relatively large amplitude and of arbitrary frequency can be generated in liquids and solids. This was accomplished by irradiating a confined, highly-absorbing liquid with a Q-switched solid state laser. The fluid expands instantly (i.e., with respect to any stress wave travel time of interest) and sends out a compressive stress wave into the test medium (any solid, liquid, or gas). However, between the confined fluid and the test medium is a thin disc of very high acoustic impedance which rings at a frequency determined by its thickness. By varying the thickness of this "ringing disc," one can generate a train of arbitrary frequency stress waves of amplitude that is essentially limited only by the energy output of the laser.

Using the above described method and a Q-switched neodymium glass laser of about 2 joule energy output, Professor Ellis and Mr. Felix have successfully generated short trains (approximately 20 cycles) of oscillatory stress waves in solids (metals and glass). These stress wave trains had typical magnitudes of ± 3000 psi and frequency of about 5×10^6 Hz. By omitting the thin, high impedance ringing disc, they have also generated solitary stress pulses (of 200-400 nanosecond duration and 5000 psi magnitude) in various metals and glass, as well as in water, which displayed a curious anelastic behavior - i.e., a purely compressive pulse developing into a compressive pulse plus a tensile tail. The origin of such anelastic behavior was at first puzzling, but most recently it has been traced to a collective effect of scattering from microscopic gas bubbles (or dislocation cavities) in the liquid (or solid).

This area of research is very much relevant to problems of material damage by pulsed lasers and of high-amplitude acoustic wave propagation in water.

Recent publications in this area include:

(1) M. P. Felix and A. T. Ellis, "Laser-Induced Liquid Breakdown-A Step-by-Step Account," Appl. Phys. Letters <u>19</u>, 484 (1971).

(2) M. P. Felix and A. T. Ellis, "Stress Pulse Propagation in Solids - A Closer Look at Dispersion" (submitted to Apply Phys. Letters for publication).

Topic #19. High-Power CW Visible Laser

Professor S. C. Lin and Dr. C. P. Wang are continuing their experimental study of the discharge and lasing characteristics of noble gas ion lasers at high current densities. Recent experiments with argon discharge in a 185 cm long segmented metal discharge tube have yielded reliable CW laser operation in the blue-green at 105 watt level, with immediate prospect of going considerably higher even without the help of stable magnetic confinement. So far, the experimental results are in good agreement with a previously developed theory by Lin and Chen for wall-confined noble gas ion lasers.

Basic understanding of noble gas ion laser discharge is essential for further development of this type of laser. With the help of stable magnetic confinement, ion lasers could conceivably be developed into an efficient source of coherent radiation operating in the near-ultraviolet and visible regions at moderately high power. Even at a few hundred watt power level, an argon ion laser operating in the blue-green region would already be a very useful radiation source for various studies of advanced laser diagnostics, underwater propagation, and scattering.

Relevant publications from this work include the following:

(1) S. C. Lin and C. C. Chen, "Kinetic Processes in Noble Gas Ion Lasers: A Review," AIAA Paper No. 70-82 (1970); AIAA Journal 9, 4 (1971).

(2) C. C. Chen, "Kinetic Processes in Noble Gas Ion Lasers," Ph.D. Thesis, University of California, San Diego, 1971.

(3) C. P. Wang and S. C. Lin, "Discharge and Lasing Characteristics of a CW Argon Ion Laser at High Current," AIAA Paper No. 72-711 (1972).

(4) C. P. Wang and S. C. Lin, "Experimental Study of Argon Ion Laser Discharge at High Current," Journal of Applied Physics, December 1972.

Topic #25. Theory of Ionospheric Heating Experiment

Profes .r J. A. Fejer and students have made important progress in their theoretical studies of parametric instabilities related to the ionospheric heating experiments. They predicted that the Bernstein mode will be excited by a pumping wave of extraordinary polarization within certain frequency bands. They also predicted that the electromagnetic mode of ordinary polarization will be excited by a pump wave of extraordinary polarization if the pump power is raised by a factor of about three above the presently used level, and excitation with the present pump power may occur at the lower frequencies at night. The line structure predicted, using uniform medium saturation theory, is sometimes seen in spectra observed at Arecibo.

Relevant publications from these studies are as follows:

(1) J. A. Fejer and E. Leer, "Excitation of Parametric Instabilities in the Ionosphere," Radio Sci. 7, 481 (1972).

(2) J. A. Fejer and E. Leer, "Purely Growing Parametric Instability in an Inhomogeneous Plasma, J. Geophys. Res. 77, 700 (1972).

(3) E. Leer, J. A. Fejer and H. C. Chen, "Parametric Excitation of Electromagnetic Waves in the Ionosphere," submitted to J. Plasma Phys.

(4) Y.-Y. Kuo and J. A. Fejer, "Spectral Line Structure of Parametric Instabilities," submitted to Phys. Rev. Letters.

(5) Y.-Y. Kuo and J. A. Fejer, "Line Structure in the Saturation Spectrum of Parametric Instabilities," to be submitted to J. Plasma Phys.

III. REPORT OF PROGRESS IN BRIEF

Referring to the six (6) research areas cited on page 2 and the topic identification numbers given in Table 1, we are presenting here a brief report of progress during the past six months, together with a list of relevant publications, for each of the twenty-six (26) current research topics:

a. Wake Turbulence and Atmospheric Boundary Layers

Topic #1. High Temperature Entrainment (see also highlight of major accomplishments in preceding section).

INVESTIGATORS: S. C. Lin, L. Tsang, and C. P. Wang

SUBJECT DESCRIPTION: Temperature Field Structure in Strongly-Heated Buoyant Thermals

PROGRESS IN BRIEF: During the past six months, we have tried out a new co-axial, high-voltage (of the order of 20 kV) pulsed-arc discharge system. With an ignitron switch replacing the old manual switch, and a vertically oriented exploding wire, we have been successful in generating high-temperature thermal bubbles in air with a high degree of initial symmetry. High-speed framing camera luminosity pictures show continuous evolution of a nearly-spherical bubble into a turbulent toroid reminiscent of much higher energy atmospheric experiments. However, due to the lower arc impedance and shorter pulse duration associated with the high voltage discharge, the total thermal energy deposition into the bubble is found to be much smaller than that obtained in the earlier experiments. Also, the weak resistive damping associated with the lower arc impedance tends to encourage multiple discharges, which is annoying. We are currently looking into various ways of increasing the thermal energy deposition and suppressing multiple discharges in this new co-axial discharge geometry.

POSSIBLE APPLICATIONS: Ivy Owl; shock-bubble interactions; tropospheric properties related to laser propagation.

PUBLICATIONS:

1. S. C. Lin, "Laboratory Simulation of High-Temperature Entrainment," Proceedings of the ARPA Entrainment Workshop, Riverside Research Institute, New York, N.Y., October 20-21, 1970.

2. S. C. Lin and C. P. Wang, "Generation of Isolated High-Temperature Thermals by Pulsed Arc Discharges," Bull. Am. Phys. Soc., Series II, 16, 1312 (1971).

3. C. P. Wang and S. C. Lin, "Measurements of Mass Entrainment and Turbulent Mixing in Isolated Thermals," Bull. Am. Phys. Soc., Series II, 16, 1313 (1971).

4. C. P. Wang, "Motion of an Isolated Buoyant Thermal," Phys. Fluids 14, pp. 1643-1647 (1971).

5. S. C. Lin, L. Tsang, and C. P. Wang, "Temperature Field Structure in Strongly-Heated Buoyant Thermals," Phys. Fluids, 16, December 1972.

6. C. P. Wang, "Motion of a Turbulent Buoyant Thermal in a Calm, Stably-Stratified Atmosphere," (submitted to Physics of Fluids).

Topic #4. Turbulence in Atmospheric Boundary Layers

INVESTIGATORS: C. W. Van Atta, T. T. Yeh, and students

SUBJECT DESCRIPTION: Atmospheric boundary layers and turbulence research.

PROGRESS IN BRIEF:

Preparation of a paper "A Laboratory Study of the Turbulent Ekman Layer," with D. Caldwell and K. Helland which recently appeared in Journal of Geophysical Fluid Mechanics, completed our work on the planetary boundary layer. A paper "Measurements of Higher-order Moments with Constant-Temperature Anemometers," by Ken Helland (in preparation) summarizes some of the work of last year on this subject. Helland also did a good deal of work on dynamic response of anemometers this past year. Measurements of structure functions of turbulent velocity fluctuations in the atmospheric boundary layer confirmed to high-order (eighth) the validity of the modifications due to intermittency of Kolmogorov's theory for the inertial subrange.

Some recent work is on measurements of the rescaled range for a variety of turbulent flows to study long term persistence and to compare with results from geophysical data which exhibit the Hurst phenomenon. We have for the first time observed the long term behavior predicted

theoretically. We have also found a universal scaling which may collapse all existing data including hydrologic data from the Nile, Mississippi, and Missouri Rivers.

POSSIBLE APPLICATIONS: Optics problem related to atmospheric transmission. Underwater technology.

PUBLICATIONS:

1. T. T. Yeh, "Scalar Spectral Transfer and Higher-Order Correlations of Velocity and Temperature Fluctuations in Heated Grid Turbulence," Ph.D. Thesis, Univ. of California, San Diego, (1971).

2. D. R. Caldwell, C. W. Van Atta and K. N. Helland, "A Laboratory Study of the Turbulent Ekman Layer," Geophys. Fluid Dynamics 3, 125-160 (1972).

3. C. W. Van Atta and J. Park, "Statistical Self-Similarity and Inertial Subrange Turbulence," Proc. of Symposium on Statistical Models and Turbulence, Lecture Notes in Physics, No. 12, Springer-Verlag (1972).

4. C. W. Van Atta and T. T. Yeh, "Spectral Energy Transfer of Scalar and Velocity Fields in Heated Grid Turbulence," (submitted to J. Fluid Mechanics).

Topic #5. Scalar Mixing and Turbulent Shear Flow (see also highlight of major accomplishments in preceding section).

INVESTIGATORS: C. H. Gibson and students

SUBJECT DESCRIPTION: Field and laboratory experiments on turbulent shear flow and scalar mixing.

PROGRESS IN BRIEF: Professor C. H. Gibson and his students are continuing their basic research works on a wide variety of problems related to turbulent shear flow and scalar mixing in the atmosphere and in the ocean. Most of their research projects are multipli-funded. Experimental facilities used in the measurements include water tunnel and mercury flow channel in the AMES Department laboratory, the Scripps Research Vessel FLIP - used in two expeditions last year, as well as the UCSD DC-3 aircraft used in conjunction with the expeditions to measure turbulence and temperature related to optical propagation

over the open ocean funded jointly by the National Science Foundation and the Air Force Cambridge Research Laboratories. The results of scalar mixing by turbulence in the three fluids of widely different Prandtl number (i.e., water, air, and mercury) were reported at the IUTAM Congress in Moscow this summer as one of 50 papers from the U.S. selected from over 350 submitted. Two important differences were discovered between the optical propagation characteristics of the atmosphere over water compared to the atmosphere over land: the humidity-temperature correlation makes a much larger contribution to the refractive index fluctuations, and the length scale of the fluctuations is much smaller compared to the height in the boundary layer over land. Other investigations receiving ARPA support include an analysis of turbulent reacting surfaces, studies of the intermittency of turbulence and thermal fine structure at high Reynolds number and measurement of various universal similarity constants of turbulence and mixing over a variety of conditions of Reynolds and Prandtl number. Closely related work on measurements in a turbulent stratified medium were carried out in the Pacific Equatorial Undercurrent (Cromwell Current) and the Mixed Layer sponsored by ONR.

POSSIBLE APPLICATIONS: Laser propagation. Underwater technology.

PUBLICATIONS: (Partial support from ARPA/IPAPS acknowledged):

1. C. H. Gibson and J. P. Clay, "Measurements of Turbulent Temperature in Mercury, Air and Water," paper presented at the IUTAM 13th Congress, Moscow, August 1972.

2. J. P. Clay and C. H. Gibson, "Power Law Comparison of Turbulent Temperature Spectra," Abstract for the 25th Annual Meeting for the Division of Fluid Dynamics of the Am. Phys. Soc., November 1972.

3. L. A. Vega, J. P. Clay and C. H. Gibson, "Fine Scale Measurements of Velocity and Temperature in the Mixed Layer of the Ocean," Abstract for 25th Annual Meeting for Division of Fluid Dynamics of the Am. Phys. Soc., November 1972.

4. G. R. Stegen, C. H. Gibson and C. A. Friehe, "Measurement of Momentum and Sensible Heat Fluxes over the Open Ocean," J. Phys. Oceanog. (scheduled for publication in January 1973).

5. C. H. Gibson and R. B. Williams, "Measurements of Turbulence and Turbulence Mixing in the Pacific Equatorial Undercurrent, Proc. Int. Symposium on Oceanography of the South Pacific, Wellington, New Zealand, February 1972 (to be published in August 1973).

b. Turbulent Mixing and Shear Flows

Topic #2. Strong Temperature Mixing by Turbulence

INVESTIGATORS: S. C. Lin and Samuel Lin

SUBJECT DESCRIPTION: Experimental study of strong temperature mixing in nearly homogeneous, isotropic turbulence in a compressible fluid.

PROGRESS IN BRIEF: We have been successful in the generation of nearly homogeneous, isotropic turbulence with rather large temperature and density fluctuations in a compressible medium. The turbulence field was generated in a subsonic wind tunnel of 1/2 meter square cross-section by rapid mixing of 64 alternately hot and cold air streams behind a specially constructed grid. Electric heating power up to 300 kW is used to generate initial temperature ratio across adjacent streams up to about 5/3 at a mean flow velocity of 11 m/sec. The downstream root-mean-square temperature fluctuations so generated is of the order of 2 percent the mean absolute temperature. This is a factor of about 20 greater than that observed in the most strongly heated grid experiment previously reported in the literature. The rate of decay of the root-mean-square temperature fluctuations, power spectrum, probability density distribution, and other statistical properties of the turbulent temperature field have been measured and analyzed. The detailed results have been summarized in a paper recently submitted to the Physics of Fluids.

Even though this experiment was originally motivated by problems of strong temperature mixing due to turbulence related to hypersonics wakes and high-temperature entrainment (Ivy Owl), our existing laboratory facilities for generating air turbulence with large-amplitude temperature (and hence refractive index) fluctuations under controlled conditions seem ideally suited for the study of a number of other interesting applied physics problems, such as optical and laser propagation through the earth's turbulent atmosphere, optical properties of unpremixed chemical laser medium, etc.

POSSIBLE APPLICATIONS: High temperature entrainment; plume physics; reentry physics; chemical laser; optical and laser propagation.

PUBLICATIONS:

1. S. C. Lin and S. C. Lin, "Homogeneous Turbulence with Large Amplitude Temperature-Density Fluctuation," Bull. Am. Phys. Soc., Series II, 16, 1312 (1971).

2. S. C. Lin and S. C. Lin, "A Study of a Homogeneous Compressible Turbulence Field Generated by Rapid Mixing of Hot and Cold Streams," AIAA Paper No. 72-119 (1972).

3. S. C. Lin and S. C. Lin, "A Study of Strong Temperature Mixing in Subsonic Grid Turbulence," (submitted to the Physics of Fluids).

Topic #3. Turbulence in Stratified Flow

INVESTIGATORS: T. T. Yeh, C. W. Van Atta, and S. C. Lin

SUBJECT DESCRIPTION: Experimental and theoretical study of turbulence in strongly-stratified flows.

PROGRESS IN BRIEF: This is a new research topic which has only been initiated during the last few months in response to recently expressed ARPA interests in problems related to interactions between turbulence and stratified flows. Since a suitable experimental facility does not yet exist, our initial efforts have been in the design and construction of a multi-layer continuous-flow water channel capable of being strongly stratified by salinity variations. The water channel will have a rectangular test section of 30 cm × 60 cm cross-section and a 500 cm length. The 12 salinity-stratified flow layers will be separately driven by 12 variable-speed motors and supplied by 12 separate salt-water storage tanks. By varying the speed of the driving motors and the salt concentration in the supply tanks, one hopes to be able to generate initial flow velocity and fluid density profiles of arbitrary shape (to the extent that they may be approximated by 12-point polynomials) up to a maximum mean flow velocity of 2 meters per second. Efforts will be made to damp out all initial flow disturbances due to propeller action, bents, and partitioning wall boundary layers before the flow enters the test section, so that controlled turbulence-stratified flow interactions can be studied down to relatively low levels. At a uniform flow velocity of 25 cm/sec under the most-stably-stratified condition, the flow channel will have a mean flow Reynolds number of 2×10^3 per cm and a channel-length/Väisälä wavelength ratio of about 6. This would bring us

within range of studying the turbulent wake collapse phenomenon directly in a continuous flow facility for the first time.

At the time of writing of this progress report, engineering design of the stratified flow channel has been completed and ordering of structural material is under way.

POSSIBLE APPLICATIONS: Undersea technology; oceanography.

PUBLICATIONS: None.

Topic #6. Turbulent Flows with Fast Chemical Reactions

INVESTIGATORS: C. H. Gibson and P. A. Libby

SUBJECT DESCRIPTION: Distribution of reactants and products near a reacting surface in unpremixed turbulent flows with very fast two-reactants chemical reactions.

PROGRESS IN BRIEF: The structure of a reacting surface in a turbulent flow involving contiguous volumes of fluid with one reactant present and the other absent has been studied by an idealized model. The analysis provides estimates of the several characteristic length scales involved and distributions of the reactants and product in the neighborhood of such a surface in fluids where the diffusivity of chemical species is much less than that of momentum (e.g., aqueous solutions). The results of an earlier experiment involving the turbulent mixing of weak-acid and weak-base solutions are discussed and are shown to provide qualitative support for the picture of reacting surfaces evolving from this study.

POSSIBLE APPLICATIONS: Undersea technology.

PUBLICATIONS:

1. C. H. Gibson and P. A. Libby, "On Turbulent Flows with Fast Chemical Reactions. Part II. The Distribution of Reactants and Products Near a Reacting Surface," Combustion Science and Technology, 6, pp. 29-35 (1972). (Jointly sponsored by ARPA under Contract No. DA-31-124-ARO-D-257, ONR under Contract N00014-67-0226-0005 (Subcontract No. 4965-26) as part of Project SQUID, and NSF Grant No. GA-31439.

Topic #7. Scalar Diffusion and Space-Time Correlation in Turbulent Flow

INVESTIGATORS: P. A. Libby and Students

SUBJECT DESCRIPTION: Dispersion and diffusion of passive scalar quantities in turbulent velocity field. Space-time correlation of velocity and temperature.

PROGRESS IN BRIEF: Our main effort over the past several years concerns measurements of various statistical properties of a passive scalar in turbulent flows. The dispersion of temperature and other passive scalars by turbulent transport arises in a variety of practical applications. Moreover, the fundamental properties of turbulence can be elucidated by tagging the fluid with passive scalars such as temperature. For example, the statistics of the interface between turbulent and non-turbulent regions in a flow are more easily discriminated if the temperature is used as the discriminating quantity rather than vorticity which is difficult to measure.

Paavo Sepri's work which was finished in mid-1971 was the initial effort in this direction; he measured and carried out considerable analysis of the space-time correlations of velocity and temperature downstream of a heated grid in a low speed wind tunnel.

John LaRue has completed an extensive series of measurements of temperature in the wake of a heated cylinder in a low-speed airstream. The time history of up to four "cold-wires" serving as fast response thermometers and forming a spatial array have been recorded at various downstream positions. The data reduction which is well under way involves developing from each temperature signal by suitable discrimination techniques the related 0-1 signal denoting when the probe is in and out of turbulence.

Some of the distributions of statistical quantities which can be extracted from the data and which in the main have never been measured before are: the intermittency function; crossing frequency; average time duration of turbulent flow; conditioned zone and point statistics of the temperature fluctuations; convection velocities of leading and trailing edges of the interfaces; and correlations in space and time of the temperature fluctuations with the 0-1 signals. (John LaRue's work was supported 50% by ARPA and 50% by AFOSR under the THEMIS program.)

Carl Scragg has completed a small theoretical study and is presently carrying out an experimental study concerned with another case of temperature dispersion, that behind a heated wire downstream of a turbulence grid. Close in to the wire the tagged, i.e., heated fluid, forms a thin sheet which is distorted and stretched by the turbulence. This stretching combined with molecular diffusion evolves to such an extent that a fully developed turbulent wake exists further downstream. This process is of fundamental importance; analogous stretching and molecular diffusion occur in the superlayer between turbulent-non-turbulent regions and between zones in a reacting turbulent flow with one reactant present and one absent.

Application of the fast response instrumentation and techniques of digital analysis we have on hand can generate new data which will provide fresh insight to these processes. For example, Carl Scragg is measuring the two-point space correlation of temperature at various downstream positions from the wire in order to establish quantitatively the dispersion of the heated fluid and the development of a full turbulent wake.

As an interesting side issue, we were able to correlate a wide variety of data on mean temperature behind such a wire, i.e., for various grid sizes, tunnel speeds, and wire locations by extending the Prandtl energy method. This method is generally applied to determine the eddy viscosity in turbulent shear flows; the crucial step in our analysis was selection of a suitable length scale.

Even though these works were originally motivated by the hypersonic wake problem in reentry physics, some of the experimental techniques and results are applicable to the high-temperature entrainment and rocket plume problems. With suitable modifications (e.g., changing the working fluid from air to water), some of the experimental and analytical techniques can also be used in the study of turbulent dispersion and diffusion problems related to undersea technologies.

POSSIBLE APPLICATIONS: Reentry physics; high-temperature entrainment; plume physics; undersea technology.

PUBLICATIONS:

1. P. A. Libby and C. Scragg, "On the Diffusion of Heat from a Line Source Downstream of a Turbulent Grid," (submitted to the AIAA Journal).

c. High-Temperature Gas Dynamics

Topic #8. Combustion Instability and Laser

INVESTIGATORS: F. A. Williams and student

SUBJECT DESCRIPTION: Study of L^* instability[1] in solid rocket combustion chambers, with possible application to visible chemical laser generation.

PROGRESS IN BRIEF: This is a new research topic recently initiated by Professor F. A. Williams and one of his students. An L^* burner[1] with transparent side walls will be constructed should extra funds become available. Using JPN (a double-base nitrocellulose-nitroglycerine solid propellant[2]) as liner, the burner is designed to operate at chamber pressures from 1 to 5 atmospheres, and at oscillation frequency from 1 to 100 Hz. Spectra will be taken, both with and without an optical cavity, with time resolution better than 10 msec. It is proposed to scan the visible spectrum for signs of lasing on a time-resolved basis. Special attention will be paid to the electronic bands of CO and NO. Since nitrocellulose self-deflagrates at pressures below 5 torr, thought will be given to the construction of reduced-pressure chambers for L^* instability. The experimental work is relatively straightforward, but at present the chance of obtaining interesting results apparently cannot be estimated theoretically.

POSSIBLE APPLICATIONS: Plume physics; laser technology.

PUBLICATIONS: None.

References:

1. M. Barrere, A. Jaumotti, B. Fraeijs de Veubeke, and J. Vandenkerckhove, Rocket Propulsion (Elsevier Publishing Co., New York, 1960), p. 653.

2. M. Barrere et al., loc. cit., p. 208.

Topic #9. Effects of Radiation on Blast Waves

INVESTIGATORS: D. B. Olfe and student

SUBJECT DESCRIPTION: Effects of radiative transfer on blast wave propagation and structure.

PROGRESS IN BRIEF: Research is being completed on the effects of transparent gas radiation on blast waves. This work has relevance to blast waves produced by focused laser radiation, as well as to supernovae remnants. The only previous theory for a point explosion with transparent gas radiation is the astrophysicists' crude model of a blast wave which starts out adiabatically, and then, when radiation becomes important, the flow instantaneously switches over to a momentum-conserving shell (zero interior pressure). Our analytical work shows that in general the transition to the momentum-conserving shell is not complete since the cooling wave has a decreasing rate of propagation into the interior. Our direct numerical computations confirm the long-time behavior of our analysis and also provide the details of the transition period. Work on the effects of absorbing gas radiation on blast wave propagation is continuing.

POSSIBLE APPLICATIONS: Plume physics; dynamics of shock waves produced by focused laser radiation in gases; momentum and energy transfer in pulsed laser-solid interactions; astrophysics.

PUBLICATIONS:

1. D. B. Olfe and F. Y. Su, "Radiative Transfer Effects on Reflected Shock Waves. I. Transparent Gas," Phys. Fluids 14, 2636 (1971).

2. D. B. Olfe and F. Y. Su, "Radiative Transfer Effects on Reflected Shock Waves. II. Absorbing Gas," Phys. Fluids 15, 263 (1972).

Topic #10. Two-Dimensional Radiative Transfer; Rayleigh-Taylor Instability

INVESTIGATORS: D. B. Olfe and student

SUBJECT DESCRIPTION: Comparison of analytical and numerical methods for treatment of two-dimensional radiative transfer problems; study of Rayleigh-Taylor instability in shock layers due to radiative transfer effects.

PROGRESS IN BRIEF: Two-dimensional radiative transfer studies are being carried out in order to test and develop computational methods. Essentially all past work has involved the one-dimensional approximation to the radiative transfer. As an example problem we have computed the radiative equilibrium temperature distribution in a gray gas within a rectangular enclosure, with its walls at different temperatures. Calculations are carried out analytically using our previously developed "modified differential approximation," and compared with numerical computation using Hottel's zonal method. In addition, an iterative procedure based on these solutions is being used to test the accuracy of the results.

Study of Rayleigh-Taylor instability is being started. First, the radiating blast wave of Topic #9 above shows very large accelerations and decelerations during the transition period, which may result in instabilities producing the "turbulent" structure observed in supernovae remanents. Another Rayleigh-Taylor instability problem being considered involves a stagnation point between two fluids. Such a study should indicate the stability of ablation layers under high decelerations, experienced, e.g., by a Jupiter probe or by a vehicle with a very high earth reentry velocity.

POSSIBLE APPLICATIONS: Ivy Owl; plume physics; high-temperature entrainment; reentry physics.

PUBLICATIONS: None

Topic #11. Gas-Surface Interactions

INVESTIGATORS: D. R. Miller and student

SUBJECT DESCRIPTION: Molecular beam studies of gas-surface interactions when inert and active gas atoms or molecules in the energy range 0.006-2 eV are impinged on metallic surfaces.

PROGRESS IN BRIEF: An investigation of the interaction of inert gases (He, Ne, Ar) on a metal (silver) in the energy range 0.006-2 eV has been completed. Direct measurements were made of the velocity distribution for the scattered atoms.

Low energy helium was studied[1] in the hopes of obtaining a useful probe to determine the surface dispersion relationship for metals; which is the fundamental relationship which must go into any surface

theory to obtain macroscopic variables such as heat capacity, absorption characteristics, energy exchange coefficients, etc. Our measurements showed that pure surface modes are apparently not easily excited in (111) metals. The technique appears very promising, however, and we are seeking funds through NSF to continue them.

Our high energy, epithermal, studies with neon and argon showed that lattice structure became important at penetration distances approaching the nearest neighbor distance. The initial effect, < 1 eV, was to spread the scattering elastically. However, the energy transfer process was still dominated by the near normal (head-on) type collision - a result which should be useful to theoreticians. All qualitative features agreed with classical numerical calculations, indicating their applicability. A comprehensive paper is in press.[2]

We are preparing to study metal-fluorine reactions with our beam techniques (F, F_2 on W, Ni). These studies will look at the effects of internal degrees of freedom (rotational and vibrational) at metal boundaries, as well as recombination, dissociation and reaction of F and F_2. Such data should be of interest to researchers working with chemical lasers containing fluorine compounds.

POSSIBLE APPLICATIONS: Plume physics; mid-course phenomena; chemical lasers.

PUBLICATIONS:

1. D. R. Miller and R. B. Subbarao, "Properties of 0.01 eV Helium Atoms Scattered Inelastically from Silver (111)," J. Vacuum Science and Technology 9, 808 (1972).

2. D. R. Miller and R. B. Subbarao, "Velocity Distribution Measurements of 0.06-1.4 eV Argon and Neon Atoms Scattered from the (111) Plane of a Silver Crystal," J. Chem. Phys. (in press).

Topic #12. Chemical Reactions in Crossed Molecular Beams

INVESTIGATORS: D. R. Miller and students

SUBJECT DESCRIPTION: Generation of energetic molecular beams for chemical kinetic studies of endothermic reactions; crossed-beams experiments.

PROGRESS IN BRIEF: To extend our molecular beam studies to highl, endothermic chemical reactions, we must study high temperature, mixed gas expansions. Such work is also very relevant to rocket exhaust plume studies. We have completed a study of binary mixture expansions, involving He, Ne, Ar, and Kr from 300 K to 2000 K, wherein we measure the terminal velocity distribution function for each species. We have been able to correlate mean velocity and temperature for each species with a parameter utilizing the dispersion, C_6, constant-derived by assuming that attractive C_6/r^6 forces dominate the collisions.

In addition, we have observed non-Boltzmann velocity distribution in gas-mixtures and are attempting to study the correct form of the distribution and its evolution in the expansion. Initial results have been presented[1] and a comprehensive paper is in preparation for publication in the Physics of Fluids.

In crossed-beams experiments, our initial emphasis has been on the reaction $O + CS_2 \rightarrow CS + SO$. We have observed product SO with our original detection system. We have been able to put an upper limit on the cross-section, based on measurements in the rebound direction (favored by theory), of 2 ± 1 Å^2. However, we qualitatively see an increase in cross-section toward the center-of-mass direction. Unfortunately, the signal to noise was too poor in the original system to pursue this. We have therefore reconstructed the entire experiment, incorporating digital counting techniques for the quadrupole mass spectrometer. We finally received all components late this spring, assembled them this summer, and now have them functioning properly.

The crucial concern at present is adequate pumping on the mass spectrometer ionizer. We are calibrating the detector with elastic scattering. Some initial runs with CS_2 have again shown product SO. It seems the cross-section is lower than anticipated from simple collision models. We will complete this study this fall.

We are preparing to use our new system to study the exothermic metal-oxide reactions, some of which have very large cross-sections. We hope to be able to use both time-of-flight mass spectrometry and emission spectroscopy to examine the cross-sections and energy distributions of the products. Because of known product excitation these systems are of great interest to laser technology.

POSSIBLE APPLICATIONS: Plume physics; chemical laser, Ivy Owl.

PUBLICATIONS:

1. D. R. Miller and D. F. Patch, "Non-Equilibrium Slip Effects in Free Jet Expansions of Binary Mixtures at High Temperatures," paper presented at the 8th Rarefied Gas Dynamics Symposium, Stanford, California, July 10-14, 1972.

Topic #13. <u>Shock Tube Measurements of Metal Oxides f-Numbers</u>

INVESTIGATORS: S. S. Penner, K. G. P. Sulzmann and students

SUBJECT DESCRIPTION: Absolute band-intensity measurements on FeO and AlO in a shock tube.

PROGRESS IN BRIEF: In conjunction with our near-ultra violet and far-infrared band-intensity measurements for FeO, we have encountered considerable experimental difficulties with the preparation of reproducible test-gas mixtures containing initially small, known concentrations of $Fe(CO)_5$ in an Ar-O_2-bath.

The sources of the difficulties are summarized below.
(a) The relatively low dissociation energy (~ 46.5 kcal/mole) of iron-pentcarbonyl causes instabilities of $Fe(CO)_5$ with respect to thermal-, light-, and surface-interactions which, together with chemical reactions leading to the formation of iron-monocarbonyl, result in the release of CO and excessive vapor pressures.

(b) Selective wall adsorption and desorption of $Fe(CO)_5$ leads to false results when conventional dilution of dynamically premixed $Fe(CO)_5$-Ar-O_2 gases is attempted in a pressure tank.

We have now learnt how to handle this complex chemical system. Thus, we purify the iron-carbonyl prior to each shocktube run by pumping off the volatile decomposition products of $Fe(CO)_5$ under

vacuum at temperatures between the boiling point of liquid nitrogen and the freezing point of H_2O. The test-gas mixtures are prepared dynamically by flowing the Ar-O_2 bath-mixtures through $Fe(CO)_5$ at a temperature near or below 0°C, and by simultaneously flushing the shock-tube test-section with the evolving $Fe(CO)_5$-Ar-O_2 mixtures at the initial pressure desired for the test-run.

In the course of our purification procedure, we have measured the vapor-pressure of pure $Fe(CO)_5$ as a function of temperature between +25 and -20°. We found excellent agreement between our data and the careful measurements by Trautz and Badstübner[1] obtained between 0 and 104°C. However, with decreasing temperature, we observed increasing deviation towards lower vapor-pressures from the usually quoted[3] measurements by Dewar and Jones.[2] The errors amount to more than a factor of five at -20°C.

We are currently accumulating f-number data on selected weak lines of Fe which will provide us with a quantitative check on the validity of our gas-preparation procedures by comparing these data with independent f-number measurements. Completion of our absolute intensity measurements for the electronic band systems and the infrared fundamental-band systems of FeO is now expected about March 1973.

We propose to continue absolute intensity measurements for electronic and vibration-rotation bands of metal oxides, particularly of AlO, during the next contract year.

POSSIBLE APPLICATIONS: Ivy Owl; plume physics.

PUBLICATIONS:

1. H. Fissan and K. G. P. Sulzmann, "Absorption Coefficients for the Infrared Vibration-Rotation Spectrum of FeO," J. Quant. Spectrosc. Radiat. Transfer 12, 979 (1972).

References:

1. M. Trautz and W. Badstübner, Ztschr. Elektrochem. 35, 799 (1929).

2. J. Dewar and H. O. Jones, Proc. Roy. Soc. 76. 558 (1905).

3. Anonymous, "Vapor Pressure of $Fe(CO)_5$," U.S. Bureau of Mines, Bull. 601, U.S. Dept. of Commerce, Washington, D.C., 1962.

d. Ionospheric Physics

Topic #24. ELF Wave Propagation

INVESTIGATOR: H. G. Booker

SUBJECT DESCRIPTION: Theoretical investigation of extremely low frequency electromagnetic wave propagation between the earth's surface and the ionosphere.

PROGRESS IN BRIEF: Professor H. G. Booker has been studying the problem of extremely low frequency electromagnetic wave propagation between the earth's surface and the ionosphere while he was on sabbatical leave at the Groupe de Recherches Ionosphériques in Paris, France. This problem arises out of the Sanguine controversy. This is a project of the United States Navy to establish in Wisconsin a high-powered transmitter for communication with submerged nuclear submarines. It would operate at extremely low frequencies in the range from 45 to 75 hertz. This project has been criticized by members of the electrical engineering department at the University of Wisconsin as technically unsound. Professor Booker was the chairman of a committee of the National Academy of Sciences and National Academy of Engineering appointed to investigate these charges. The Committee reported some months ago. This stimulated his preexisting desire to investigate the propagation of electromagnetic waves in the range from 3 to 3000 hertz.

From HF frequencies of the order of 10 megahertz down to VLF frequencies of the order of 10 kilohertz, heights of reflection of electromagnetic waves from the ionosphere decrease progressively. This creates the impression that at extremely low frequencies such as 45 to 75 hertz, levels of reflection in the ionosphere must be very low. For this reason it is customarily assumed that reflection occurs at a level where the electronic collisional frequency is greater than the electronic gyro frequency. In these circumstances the reflecting medium would have properties similar to that of a metal of low density and the earth's magnetic field would be unimportant. The ionospheric losses experienced in propagating a radio wave along the transmission line formed by the earth and the ionosphere would be similar to the metal losses experienced in an ordinary transmission line. However, Professor Booker's work is showing that there is in fact a frequency, of the order of 10 kilohertz, at which the height of reflection from the ionosphere is at a minimum. Not only does the height of reflection increase as one goes up in frequency from about 10 kilohertz, it also

increases as one goes down in frequency. As a result, heights of reflection at 45 to 75 hertz are significantly greater than one would gather from the existing literature. They in fact occur at a level where the electronic collision frequency is small compared with the electronic gyro frequency. As a result conductivity is unimportant and the earth's magnetic field is essential to understanding what is happening. The ionospheric losses experienced by radio waves propagating in the transmission line formed by the earth and the ionosphere is not primarily a conductivity effect at all. This is due to leakage into the upper ionosphere of the waves that propagate around the lines of force of the earth's magnetic field producing the whistler phenomenon.

Professor Booker proposes to investigate this problem more thoroughly, using a new analytical method which he has recently developed in Paris.

POSSIBLE APPLICATIONS: Submarine communication; geophysics and ionospheric physics.

PUBLICATIONS:

1. H. G. Booker, "The Ionosphere as the Secondary Conductor of a Transformer at ELF," (paper submitted for presentation at the URSI Meeting, Williamsburg, Va., December 1972.)

Topic #25. <u>Theory of Ionospheric Heating Experiment</u> (see also highlight of major accomplishments in Section II)

INVESTIGATORS: J. A. Fejer and students

SUBJECT DESCRIPTION: Theoretical studies of parametric instabilities related to the ionospheric heating experiment at Arecibo.

PROGRESS IN BRIEF: Professor J. A. Fejer and his students are continuing their studies on a number of problems related to the ionospheric heating experiment.

On the problem of excitation of parametric instabilities by radio waves in a magnetoplasma, a uniform medium is assumed and linear approximations are used. Excitation by a pump wave of ordinary polarization is found to be hardly affected by the magnetic field. Low or zero frequency ion waves and high frequency Langmuir waves are

excited simultaneously. For an extraordinary pump wave the excited high frequency electrostatic waves are in the Bernstein mode. The threshold is slightly higher and excitation can occur only within certain "allowed" frequency bands. A new type of parametric instability in which the excited waves are electromagnetic in nature and which is more strongly affected by the inhomogeneous nature of the medium, is discussed qualitatively.

A simple method based on energy balance is used first to rederive the well known threshold condition for the purely growing parametric instability in a homogeneous medium and later to estimate the effects of inhomogeneity in a semiquantitative manner. A method different from that of Perkins and Flick is then used to calculate the threshold in a more quantitative manner for the case where the effects of inhomogeneity dominate over those of collisions. The result agrees with that of Perkins and Flick for $k_{\parallel}\ell >> 1$ in their terminology. For $k_{\parallel}\ell << 1$ neither theory is directly applicable and the threshold is obtained by numerical methods. The present method of calculation has the advantages that its range of validity is easily checked, that it provides good physical insight and that it is easily applicable to electromagnetic instabilities. The threshold for excitation of ordinary waves by an extraordinary pump wave in an inhomogeneous plasma is then calculated using a method previously used to study electrostatic instabilities. This threshold may be exceeded in the Boulder modification experiment, and density irregularities will then develop in a wide region some 10 km below the pump reflection level.

On the problem of spectral structure in parametric instabilities, the nonlinear saturation spectrum is shown to be restricted to discrete values of the propagation vector if spontaneous emission is neglected. This "line spectrum" is computed for the decay instability. The purely growing instability is not excited for equal ion and electron temperatures if the pump power is less than 3.5 times the threshold power of the decay instability.

A tentative theory is developed which explains the line structure of the saturated spectrum excited by powerful radio transmissions and diagnosed by the 430 MHz radar at Arecibo.

The important conclusions drawn from these studies may be summarized as follow:

(i) It is predicted that the Bernstein mode will be excited by a pump wave of extraordinary polarization within certain frequency bands.

(ii) It is predicted that the electromagnetic mode of ordinary polarization will be excited by a pump wave of extraordinary polarization if the pump power is raised by a factor of about three above the presently used level; excitation with the present pump power may occur at the lower frequencies at night.

(iii) The line structure predicted, using uniform medium saturation theory, is sometimes seen in spectra observed at Arecibo.

POSSIBLE APPLICATIONS: Ionospheric heating experiment; laser interaction with plasmas.

PUBLICATIONS:

1. J. A. Fejer and E. Leer, "Excitation of Parametric Instabilities in the Ionosphere," Radio Sci. 7, 481 (1972).

2. J. A. Fejer and E. Leer, "Purely Growing Parametric Instability in an Inhomogeneous Plasma," J. Geophys. Res. 77, 700 (1972).

3. E. Leer, J. A. Fejer and H. C. Chen, "Parametric Excitation of Electromagnetic Waves in the Ionosphere," submitted to J. Plasma Phys.

4. Y.-Y. Kuo and J. A. Fejer, "Spectral Line Structure of Parametric Instabilities," submitted to Phys. Rev. Letters.

5. Y.-Y. Kuo and J. A. Fejer, "Line Structure in the Saturation Spectrum of Parametric Instabilities," to be submitted to J. Plasma Phys.

Topic #26. Nonlinear Interactions between Electromagnetic Waves and Plasmas

INVESTIGATORS: G. J. Lewak and students

SUBJECT DESCRIPTION: Theoretical studies of nonlinear interactions between electromagnetic waves and plasmas. (Jointly sponsored by NASA and ARPA, with funding support in the approximate ratio of 60% NASA and 40% ARPA).

PROGRESS IN BRIEF: Professor G. J. Lewak and his students are continuing their theoretical studies on a number of problems related to non-linear interactions between electromagnetic waves and plasmas. These include subharmonics generation, wave-wave interactions, plasma turbulence, and plasma boundary effects.

On subharmonics generation in a plasma, the one-half subharmonic of the electron-plasma wave has been analyzed and it was found that a threshold amplitude of the fundamental is required before the subharmonic can obtain energy from the fundamental and grow. An amplitude dependent dispersion relation for the subharmonic was obtained and was analytically investigated only for the case of cool plasmas. Numerical analysis is needed in general and may lead to more interesting results. The approximate analysis shows that in the Allouette experiments the threshold amplitude could have been resolved especially if the ionospheric plasma contained some energetic electrons.

On wave-wave interactions, their analysis showed that the case of three scalar waves could be analyzed (independently of the plasma model used) in terms of only two independent parameters. The use of conservation laws and other general relations enabled us to obtain relations between coupling parameters which must hold in general and which are therefore a useful check on any specific calculation.

On plasma turbulence, the problem of propagation of a test wave through a plasma containing a random spectrum of electromagnetic waves is investigated. The effect of a random spectrum of plasma waves (i.e., electrostatic waves) on the propagation properties of a low frequency wave (such as the ion acoustic wave) has been analyzed by Vedenov and Rudakov (Soviet Phys. Doklady, 9, 1073 (1965)) who found that the test ion acoustic wave could even become unstable and grow for a suitable spectral distribution of the plasma waves. A similar effect is expected in the case of an E. M. wave spectrum and is relevant to the understanding of wave propagation through the magnetospheric plasma, which according to Kennel and Petcheck's model (as well as observations) contains a spectrum of whistler mode waves. A test wave could then lead to an instability with the possible production of a new wave. This could therefore be a reason for the observed "triggered emissions."

A further application of this theory could be relevant to the Ionospheric Heating Experiment, where a spectrum of waves is produced through parametric instabilities. The effect of this spectrum

on the probing waves then needs to be understood in order that the experimental results may be correctly interpreted.

This problem is in progress at the present time. Definite results are expected very soon for a simplified case of a spectrum of whistler mode waves propagating almost parallel to the magnetic field and a test wave which is either a low frequency whistler or an ion acoustic wave.

On plasma boundary effects, the reflection and transmission coefficients for obliquely incident waves on a plasma boundary were obtained in second order perturbation theory. It was shown that corrections due to finite temperature effects were entirely relativistic and that therefore the relativistic Vlasov equation must be used if these effects are important. This contrasts with the use by previous authors of the nonrelativistic Vlasov equation.

POSSIBLE APPLICATIONS: Ionospheric heating experiments; space probe experiments; laser interaction with plasmas.

PUBLICATIONS:

1. E. M. Zawadzki and G. J. Lewak, "Penetration to Second Order of an Electrostatic Field into a Warm Plasma," J. Plasma Phys. 5, 73 (1971).

2. G. J. Lewak and H. J. Lee, "Fractional Harmonics in a Plasma," (in preparation).

3. G. J. Lewak, "Interaction of Electrostatic Waves in Collisionless Plasmas," J. Plasma Phys. 5, 51 (1971).

4. G. J. Lewak, "Nonlinear Interaction of Resonant Plasma Oscillations," (with J. Ogunlana), J. Plasma Phys. 7, 207 (1972).

e. Laser Propagation and Advanced Technology

Topic #14. Nonlinear Phenomena in Bound-Free Transitions Induced by Lasers

INVESTIGATORS: S. S. Penner and student

SUBJECT DESCRIPTION: Experimental study of anomalous near-ultraviolet laser propagation through molecular gases Cl_2 and NOCl.

PROGRESS IN BRIEF: Excessive transmission and pulse delays have been observed when intense laser radiation at doubled-ruby laser frequency (3471 Å) is passed through Cl_2 and Cl_2-inert-gas mixtures.[1,2] We have also observed similar anomalous behavior in preliminary studies on NOCl (which dissociates into NO and Cl). Thus, it appears likely that coherence effects are not only important in laser propagation through stable two-level systems (as has been discussed by many authors) but also in bound-free transitions. This conclusion should be of importance in assessing the ultimate limits of transmission of laser radiation through atmospheric gases. It should be noted that we have spent considerable effort in investigating the possibility that we were dealing with laser-saturated absorption in the Cl_2 and Cl_2-inert-gas mixtures rather than with a SIT-like phenomenon. However, our experimental findings are not consistent with the occurrence of bleaching waves and laser-saturated absorption.

During the next year, we propose to complete experimental studies on NOCl and NOCl-inert-gas mixtures and to perform all necessary tests to decide on the occurrence of laser-saturation or coherence effects for this molecule. An essential step in this program is the implementation of simultaneous measurements of laser transmission, pulse delays, and resonance-Raman scattering from NOCl, which will also provide us with new quantitative information on the magnitude of resonance-Raman scattering for a particular molecule.

POSSIBLE APPLICATIONS: High-power laser propagation; chemical laser.

PUBLICATIONS:

1. R. C. Sepucha and S. S. Penner, "Observations of Anomalous Transparency in Bound-Free Transitions of Cl_2," Phys. Rev. Letters 28, 395 (1972).

2. R. C. Sepucha and S. S. Penner, "Transmission of 3471 Å Laser Radiation through Cl_2 and Cl_2-Inert-Gas Mixtures," (to be submitted to Phys. Rev.).

Topic #19. High-power CW Visible Laser (see also highlight of major accomplishment in Section II)

INVESTIGATORS: S. C. Lin and C. P. Wang

SUBJECT DESCRIPTION: Theoretical and experimental study of high-power CW ion lasers operating in the visible region.

PROGRESS IN BRIEF: Recent scaling relationships obtained by Chen and Lin[1, 2] indicate that the excitation-rate-limited power output per unit length of a continuous wave (CW) argon ion laser in the absence of resonance radiation trapping should scale with the square of pR (the product of filling gas pressure p and the plasma tube radius R), while the peak generation efficiency is expected to increase linearly with pR. This is in the direction of favoring large-bore tubes and high filling pressure for higher power and more efficient laser operation up to the limit of resonance radiation trapping by the argon ions. Radiation trapping tends to impede the rate of removal of the intermediate-state ions, Ar^+ $(^3P)4s$, from the active region and hence upset the process of inversion. However, the limiting value of pR for onset of Ar^+ resonance radiation trapping has only been roughly estimated,[2] and the rates at which higher values of pR may saturate the gain and laser output power are not at all well determined.

Argon ion laser experiments have been performed in a large bore (12 mm), segmented metal plasma tube. The tube is capable of maintaining a steady state discharge current up to 500 amperes in low pressure argon without excessive contamination. The experimental results on the discharge and lasing characteristics agree with recent theory. So far the maximum visible laser output at high discharge current is not yet limited by resonance radiation trapping or other saturation effects, but rather by a low inversion-utilization efficiency. A major cause of such low utilization efficiency is presently attributable to a severe optical degradation of the dielectric cavity mirrors when the internal radiation flux density exceeds a certain limit (i.e., a few kilowatt/cm^2).

Recent experiments with a 185 cm long segmented metal discharge tube have yielded reliable CW laser operation in the blue-green at 105 watt output power level. With improved cavity mirrors, we may be able to push the output power to considerably higher levels even without the help of stable magnetic confinement.

POSSIBLE APPLICATIONS: Raman spectroscopy for remote chemical analysis and diagnostics of reactive turbulent flows; underwater technology; sea floor inspection; general high-power visible laser technology.

PUBLICATIONS:

1. S. C. Lin and C. C. Chen, "Kinetic Processes in Noble Gas Ion Lasers: A Review," AIAA Paper No. 70-82 (1970); AIAA Journal 9, 4 (1971).

2. C. C. Chen, "Kinetic Processes in Noble Gas Ion Lasers," Ph.D. Thesis, University of California, San Diego, 1971.

3. C. P. Wang and S. C. Lin, "Discharge and Lasing Characteristics of a CW Argon Ion Laser at High Current," AIAA Paper No. 72-711 (1972).

4. C. P. Wang and S. C. Lin, "Experimental Study of Argon Ion Laser Discharge at High Current," Journal of Applied Physics, November 1972.

Topic #20. Magnetic Confinement and Efficient Ion Laser Generation

INVESTIGATORS: S. C. Lin and student

SUBJECT DESCRIPTION: Theoretical and experimental study of noble gas ion laser performance under the condition of stable magnetic confinement.

PROGRESS IN BRIEF: Professor S. C. Lin and graduate student T. K. Tio are investigating the prospect of stable magnetic confinement as a means for drastically improving the generation efficiency of ion lasers. Previous studies indicated that superposition of a uniform axial magnetic field (i.e., from a solenoidal current) of suitable strength into the discharge plasma did improve the performance of noble gas ion lasers, but the effect has not been dramatic (typically, a factor of 2 improvement in output power and generation efficiency). This may be attributable to the well known fact that plasmas in uniform axial magnetic fields are susceptible to helical instabilities so that the effectiveness of the confining field is severely limited.

To achieve stable confinement, we proposed to generate the ion laser plasma within a linear, multipole, minimum-B field geometry commonly employed in controlled thermonuclear fusion research. The main experimental apparatus, which consists of a 150 cm long, 10 cm bore water-cooled quartz discharge chamber with external axial confining field windings and internal hexapole stabilizing field windings, has been designed and is currently under construction.

In the theoretical study, we plan to extend the previous works of Lin and Chen for wall-confined plasma columns to the case of minimum-B-field-confined plasma columns.

POSSIBLE APPLICATIONS: Underwater technology; undersea inspection; isotope separation.

PUBLICATIONS: None yet (on-going doctoral thesis research by graduate student).

Topic #21. Upward Laser Frequency Conversion in Gaseous Media

INVESTIGATORS: S. C. Lin and student

SUBJECT DESCRIPTION: Theoretical and experimental study of transient vibrational/rotational population in polyatomic gases, such as BCl_3 and SF_6, during resonant absorption of high-intensity infrared radiation.

PROGRESS IN BRIEF: Professor S. C. Lin and graduate student J. Morris are studying the problem of transient vibrational/rotational population in polyatomic gases, such as BCl_3 and SF_6, during resonant absorption of high-intensity infrared radiation. The objective is to search for the existence of population inversions between the upper levels of the absorbing vibrational modes and the lower levels of the non-absorbing modes that can be utilized for upward frequency conversion of high-power infrared lasers.

In the experimental program, a two-stage, electrically-pumped CO_2 laser with wavelength selection and magnetically driven shutters has been constructed to provide an initial source of moderately-intense infrared radiation in the 10.6 μ region. It is hoped that a much higher intensity pulsed infrared laser, either in the form of a double-discharge TEA-laser or an electron-beam-seeded laser, will become available for more rapid pumping of the absorbing medium.

In the theoretical program, we are currently in the process of setting up coupled rate equations for the many-level system under consideration.

POSSIBLE APPLICATIONS: High-power lasers in the near-infrared and visible regions; tunable infrared lasers.

PUBLICATIONS: None yet (on-going doctoral thesis research by graduate student).

Topic #22. Kinetics in Electron-Beam-Seeded Gas Lasers

INVESTIGATORS: S. C. Lin and C. P. Wang

SUBJECT DESCRIPTION: Theoretical and experimental study of excitation and population inversion in electron-beam-seeded gas lasers.

PROGRESS IN BRIEF: This is a new research topic recently initiated by Professor S. C. Lin and Dr. C. P. Wang in response to expressed ARPA interest in high-power laser technology, nonlinear laser propagation, laser-induced breakdown, and laser energy coupling.

The use of a high-energy electron beam (up to about 100 kV) for uniform excitation of gas lasers was first suggested by Professor S. C. Lin in 1966 to one of his former graduate students, Dr. R. A. Chodzko, as part of the latter's doctoral thesis investigations. Preliminary calculations and estimates made by Chodzko[1] indicated that the method indeed looked promising but a high-energy electron beam with sufficiently high current capacity for direct pumping of a CO_2-N_2 laser of moderate active volume appeared too expensive to develop so that the effort was discontinued. However, recent intensive works at the AVCO-Everett Research Laboratory[2,3] and elsewhere [4,5] on electron-beam-seeded or electron-beam-pumped gas lasers seem to indicate that the idea was basically sound and attractive. Furthermore, the proposition of using a secondary discharge circuit (i.e., the so-called "sustainer" stage[2,3]) for providing the bulk of the electrical pumping energy tends to reduce the current requirement and hence the cost of the high-voltage primary electron beam significantly. Thus, relatively high-power, pulsed electron-beam-seeded gas laser can now be built at relatively low cost.

Since the use of electron beam for laser excitation is still in its infancy and the method has been successfully tried only in a few

well-known gas mixtures (e.g., CO_2-N_2, H_2, and Xenon), we plan to reactivate our effort in the study of electron-beam-seeded gas lasers. To provide a suitable experimental apparatus for this study, we have recently completed the design of a high-voltage discharge system with a 12-liter active (sustainer) volume. The 100 kV hot-cathode electron beam for seeding the sustainer volume is designed to provide a pulsed beam current density up to about 1 ampere per cm^2 for about 10 μsec duration. A variable and switchable high-voltage supply is also provided for the sustainer section so that both sub-breakdown and super-breakdown discharges can be studied.

When CO_2-N_2 mixtures at or near atmospheric pressures are used as the active medium, we anticipate that pulsed laser energy of the order of 600 joule can be extracted from this apparatus in the time scale of the order of 10 μsec. This would provide a very intense infrared source for the upward frequency conversion experiment discussed in Topic #21.

POSSIBLE APPLICATIONS: High-power laser technology; nonlinear laser propagation; laser-induced breakdown and interactions.

PUBLICATIONS: None.

References

1. R. A. Chodzko, "Analysis of an Electron Beam Excited CO_2-N_2 Laser," pp. 8-9, and Appendix I, pp. 153-159 in Ph.D. Thesis entitled "Thermal Interaction of a Laser Beam in an Absorbing Gas," University of California, San Diego (1970).

2. J. D. Daugherty, D. H. Douglas-Hamilton, R. M. Patrick, and E. R. Pugh, "Laser or Ozone Generator in which a Broad Electron Beam with a Sustainer Field Produce a Large Area, Uniform Discharge," U.S. Patent No. 3,702,973, filed by the AVCO Everett Research Laboratory, September 17, 1970 (to be granted November 14, 1972).

3. D. H. Douglas-Hamilton, "Dissociative Recombination Rate Measurements in N_2, CO and He," AVCO Everett Research Laboratory, Research Report 343, November 1971.

4. N. G. Basov, V. A. Danilychev, and Yu. M. Popov, "Stimulated Emission in the Vacuum Ultraviolet Region," Soviet Journal of Quantum Electronics, 1, 18 (1971).

5. N. G. Basov, "Soviet Approach to E-Beam Pumping," Laser Focus, 8, 45 (1972).

f. Laser Diagnostics and Interactions

Topic #15. Laser-Induced Stress Wave Propagation in Solids and Liquids (see also highlight of major accomplishments in Section II)

INVESTIGATORS: A. T. Ellis and student

SUBJECT DESCRIPTION: Experimental study of laser-induced stress wave propagation in solids and liquids

PROGRESS IN BRIEF: Various investigators have used Q-switched and mode-locked lasers to generate short duration compressive stress pulses, but few have been concerned with observing the subsequent wave propagation. We have used a Q-switched neodymium doped glass laser (2 joules in 50 nanosec) to irradiate a highly absorbing and confined liquid and thereby produce a moderately high amplitude (100 to 500 bar) plane compressive stress pulse of approximately 200 to 250 nanosec duration. During propagation, we observed that the pulse shape changed in a manner neither previously expected nor observed.

The stress-time histories of the propagating stress pulse entering and leaving the specimen were measured by using X-cut quartz gauges in the displacement current mode manufactured by the Valpey Corporation. The short duration camera system used to take the photographs was the 75 nanosec camera described and used by the authors previously.[1]

The above method for generating and monitoring a plane compressive stress pulse was then used to observe the pulse propagation in various specimens. All specimens used were rods 3.81 cm in diamter and 5.08 cm in length. We found that when a short duration plane compressive stress pulse is propagated in various solid metals, the initially compressive pulse develops a tensile tail indicative of dispersion. This dispersion occurs without the stress pulse impinging upon external boundaries or upon any classically recognized internal boundaries. This phenemonon also occurs in water in which it is demonstrated experimentally that the dispersion mechanism is the scattering of the wave by the small amount of air normally present in water. It is believed that the pulse dispersion in the metals is likewise caused by scattering of the wave by the very small but extremely numerous defect related voids that exist in all metals, even if they are carefully prepared metallic single crystals.

POSSIBLE APPLICATIONS: Laser-induced material damage; high-power sonar generation and propagation; acoustic holography.

PUBLICATIONS:

1. M. P. Felix and A. T. Ellis, "Laser-Induced Liquid Breakdown--A Step-by-Step Account," Appl. Phys. Letters 19, 484 (1971).

2. M. P. Felxi and A. T. Ellis, "Stress Pulse Propagation in Solids - A Closer Look at Dispersion," (submitted to Appl. Phys. Letters).

Topic #16. Laser-Induced Elastic Wave Focusing in Partially Transparent Solids

INVESTIGATORS: W. Nachbar and student

SUBJECT DESCRIPTION: Theoretical study of laser-induced elastic wave focusing in partially transparent solids in one-dimensional geometries.

PROGRESS IN BRIEF: Analytical solutions for stress waves produced by rapid heating of cylinders and spheres show very large hydrostatic tensile stress pulses produced at and near the center in these geometries after the relief wave from the surface has progressed to the center. These short pulses of large amplitude (infinite amplitude for instantaneous energy deposition) are called stress wave focusing. Since focusing is also exhibited by the linearized hydrodynamic model as well as in the linear elastic solid, this effect should cause small cavitation bubbles to appear along the beam axis when an unfocused laser beam is passed through water.

Experiments with lasers have not been able to identify the cavitation bubbles formed in liquids with the stress wave focusing effect. The bubbles that are formed in these experiments appear to arise either from optical focusing of the laser beam itself, or through the self-focusing of "filamenting" effect, or from preferential energy absorption by minute impurities. There are several theories (e.g. dielectric breakdown) which are proposed to explain bubble formation in the case of high energy deposition into a small volume. However, the subject study has as its objectibe the investigation of damage caused by stress waves arising from impulsive heating of an appreciable volume of material in which the temperature rise itself is moderate and does not cause chemical or phase

change, and where other effects of more intensive fields can likewise be ignored.

We have been reworking the sudden heating of the cylindrical core problem to include now the assumption of a small, central hole. We want to examine the displacements of the hole boundary under the focusing stress wave. From this we expect to find out about the dynamics of enlargement of minute imperfections as an effect of the focusing stress wave.

POSSIBLE APPLICATIONS: Detection of small voids and measurement of small radiation absorption coefficients at low energy inputs; study of mechanism for fracture of glass lasers below thermal damage thresholds at moderate energy inputs.

PUBLICATION:

1. W. Nachbar and C.-H. Ho, "Thermally-Induced Elastic Wave Focusing Near a Cylindrical Cavity in a Partially Transparent Solid Under Impulsive Electromagnetic (Laser) Heating," (in preparation for publication).

Topic #17. Impulsive Stress Wave Propagation in Solids

INVESTIGATORS: G. A. Hegemier and student

SUBJECT DESCRIPTION: Theoretical study of stress and deformation states in partially transparent solids subjected to impulsive radiation.

PROGRESS IN BRIEF: Professor G. A. Hegemier and his student have been studying the problem of stress wave propagation and deformation states in partially transparent solids when they are subjected to impulsive radiation, either from an intense X-ray or an intense laser source. So far, they have obtained an exact (i.e., analytic) one-dimensional solution for elastic, viscoelastic, and plastic temperature-dependent solids occupying a half-space. They have also obtained exact two-dimensional solution for an elastic half-space subjected to a cylindrical beam of radiation. Their solutions indicate that one-dimensional simulations may lead to nonconservative results in certain cases.

Even though the one- and two-dimensional geometries are highly idealized, the closed-form (i.e., analytic) solutions they obtained are

useful not only for indication of the general character of the propagating stress waves, but also for providing a method for checking large-scale computer codes.

POSSIBLE APPLICATIONS: Simulation of impulsive X-ray or laser radiation-solid interactions; checking of computer codes.

PUBLICATIONS:

1. G. A. Hegemier and F. Tzung, "Stress-Wave Generation in a Temperature-Dependent Absorbing Solid by Impulsive Electromagnetic Radiation," J. Appl. Mech. 37, 339 (1970).

2. F. Tzung and G. A. Hegemier, "Stress-Wave Generation in an Elastic Half-Space Subjected to a Cylindrical Beam of Impulsive Radiation," (to be published in the J. Appl. Mech.).

Topic #18. Laser-Induced Plasma Instabilities

INVESTIGATORS: K. A. Brueckner and S. Jorna

SUBJECT DESCRIPTIONS: Theoretical study of laser-driven instabilities in plasmas (jointly sponsored by the KMS Fusion, Incorporated, and ARPA)

PROGRESS IN BRIEF: Professor K. A. Brueckner is continuing his study of laser-induced instabilities in absorbing media while on leave of absence from the University of California, San Diego (and for which he received no funding support from ARPA). With the collaboration of S. Jorna (a post-doctoral fellow at UCSD who received partial support from ARPA through IPAPS), he has just completed a theoretical study of laser-driven instabilities in plasmas. In particular, the study of laser-induced instabilities is generalized to the case of non-zero laser wave number. This departure from the dipole approximation indicates how the two-stream and parametric instabilities merge. A resonance in the Maxwell propagator further predicts the possible existence of an instability in the diffraction regime. Calculations show that this flux-changing mode can be excited well below the critical density with a somewhat higher threshold intensity and lower growth rate than for the parametric mode. The experimental significance of the new instability is discussed in some detail on the basis of a simple isothermal model for the plasma.

With the schedule departure of Dr. S. Jorna from the UCSD campus on October 16, 1972, ARPA/IPAPS support for this work will be terminated after that date.

POSSIBLE APPLICATIONS: Laser and electromagnetic wave propagation through the ionosphere; laser-driven fusion.

PUBLICATION:

1. K. A. Brueckner, R. A. Cover, P. Hammerling and S. Jorna, "Laser-Driven Plasma Instabilities," (submitted for publication).

Topic #23. Raman Scattering and Advanced Laser Diagnostics

INVESTIGATORS: S. C. Lin, C. P. Wang, and students

SUBJECT DESCRIPTIONS: Theoretical and experimental investigations on a number of advanced laser diagnostic techniques, including Raman scattering for remote chemical analysis, wideband laser doppler for measurement of instantaneous turbulence velocity in fluid flows.

PROGRESS IN BRIEF: Professor S. C. Lin, Dr. C. P. Wang, and a number of their students are carrying out theoretical investigation and experimental development on a number of advanced laser diagnostics techniques that are generally useful in chemical kinetics, gas dynamics, and fluid mechanics studies of interest to ARPA.

Under the supervision of Professor S. C. Lin, undergraduate students J. Levatter and R. Sandstrom have successfully constructed a pulsed nitrogen laser (with discharge geometry and operational characteristics generally similar to those of the AVCO Everett Research Laboratory Model C950 commercial unit), a high-sensitivity digital photon counter (of their own design), and a Raman scattering test cell with associated light collecting optics. Using these in conjunction with a low-noise, double-grating monochromator available at the UCSD AMES Department laboratory, they are currently remeasuring the Raman scattering cross sections for a number of common diatomic and triatomic gases at 3371 Å.

Dr. Charles C. P. Wang has made extensive comparison studies of the various optical mixing techniques commonly employed in laser doppler velocimetry and is proposing a new wideband FM-demodulation technique for measurement of instantaneous turbulence velocity in any

semi-transparent fluid. He is currently exploring this new technique with the help of undergraduate student D. Snyder.

POSSIBLE APPLICATIONS: Concentration and velocity measurements in reactive turbulent flows; underwater technology; advanced diagnostics for high-temperature entrainment and plume experiments.

PUBLICATIONS:

1. C. P. Wang, "New Model for Laser Doppler Velocity Measurement by Laser Doppler," Appl. Phys. Letters 18, 522 (1971).

2. C. P. Wang, "Instantaneous Turbulence Velocity Measurement by Laser Doppler Velocimeter," Appl. Phys. Letters 20, 339 (1972).

3. C. P. Wang, "A Unified Analysis on Laser Doppler Velocimeter," J. Phys. E: Scientific Instruments 5, 763 (1972).

4. C. P. Wang, "Measurement of Turbulence by Optical Mixing Spectroscopy," Proceedings of the Laser Doppler Velocimeter Workshop, Purdue University, March 9-10, 1972 (to be published).

IV. PERSONNEL

Professor S. C. Lin became Principal Investigator on this contract as of February 1972. Personnel involved in the above research areas are listed below. Individuals listed as faculty members or as research scientists are members of the Institute for Pure and Applied Physical Sciences.

Alferieff, Michael	Research Assistant
Bernard, Jay M.	Research Assistant
Booker, Henry G.	Professor of Applied Physics
Brueckner, Keith A.	Professor of Physics
Chen, Helen	Research Assistant
Dehmel, Richard C.	Research Assistant
Ellis, Albert T.	Professor of Applied Mechanics
Erickson, Gary G.	Research Assistant
Fedder, Joel A.	Research Assistant
Fejer, Jules A.	Professor of Applied Physics
Felix, Michael P.	Research Assistant
Gibson, Carl H.	Associate Professor of Aerospace Engineering
Gilbert, Alan G.	Research Assistant
Glatt, Leslie	Research Assistant
Hegemier, Gilbert A.	Associate Professor of Applied Mechanics
Helland, Kenneth N.	Research Assistant
Ho, Chik-Horng	Research Assistant
Horne, James M.	Research Assistant
LaRue, John C.	Research Assistant
Leuer, James A.	Research Assistant

Lewak, George J.	Assistant Professor of Applied Physics
Libby, Paul A.	Professor of Applied Mechanics
Lin, Samuel S.	Assistant Research Engineer
Lin, Shao-Chi	Professor of Engineering Physics
McConnell, Steven O.	Research Assistant
Miller, David R.	Assistant Professor of Engineering Physics
Mooradian, Gregory J.	Research Assistant
Morris, James H.	Research Assistant
Nachbar, William	Professor of Applied Mechanics
Olfe, Daniel B.	Professor of Aerospace Engineering
Penner, S. S.	Professor of Engineering Physics
Poulsen, Peter	Research Assistant
Sulzmann, Klaus G.	Research Engineer
Tio, Tjaw K.	Research Assistant
Tsang, Leslie C. H.	Research Assistant
Van Atta, Charles W.	Associate Professor of Aerospace Engineering
Walters, Dolores A.	Research Assistant
Wang, Charles C. P.	Assistant Research Engineer
Williams, Forman A.	Professor of Engineering Physics